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Herpetofaunal diversity of the disturbed and isolated Bukit Maras in Terengganu, Peninsular Malaysia

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Abstract

We present the first checklist of herpetofauna in Bukit Maras (Malaysia) based on surveys conducted from 2019 to 2023. Visual Encounter Surveys (VES) and drift-fenced pitfall traps were employed as collection methods. Our study documented a total of 55 herpetofauna species, comprising 23 amphibians and 32 reptiles. Among these, the critically endangered species, *Manouria emys* (according to the IUCN Red List) is a species of high conservation concern. The individual-based rarefaction and extrapolation sampling curves were approaching completeness, which indicates that only a few additional species could be discovered if further sampling is conducted. A species-habitat network analysis revealed variations in species composition across different habitat types. Notably, secondary forest exhibited higher herpetofaunal diversity compared to agricultural areas. Overall, the herpetofaunal diversity in Bukit Maras is relatively diverse but the observed disparity in herpetofaunal diversity between the secondary forest and agricultural areas highlights the vulnerability of forest-dependent species to habitat conversion. This suggests a significant decline in overall species richness and potential biotic homogenisation if Bukit Maras is entirely converted to agriculture.

Key Words

agricultural area, amphibians, anthropogenic disturbance, habitat island, reptiles, secondary forest, Southeast Asia

Introduction

Peninsular Malaysia harbours remarkable biodiversity (Myers et al. 2000). However, rampant deforestation threatens this richness (FAO 2022). Driven by factors like urban sprawl, logging, and agriculture, primary forest degradation has fragmented these once-continuous landscapes (Hadad et al. 2015; Magintan et al. 2017). This has resulted in isolated hills surrounded by human-modified areas. Research suggests these isolated hills can serve as refugia for displaced amphibians and reptiles, even harbouring new species discoveries (Quah et al. 2013; Grismer et al. 2014a, 2016a). Documenting herpetofaunal diversity in these areas is crucial before local populations disappear.

In the state of Terengganu, more than 308,000 hectares of native forest have been cleared for agricultural activities, primarily for oil palm, rubber plantation,

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and crop cultivation (Alam et al. 2012). Although many herpetofaunal studies had been conducted in the primary forest of this state (Grismer et al. 2013a, 2013b, 2014b, 2014c, 2015, 2016b, 2018; Chan et al. 2014; Sumarli et al. 2015, 2016; Nur Amalina et al. 2017; Shahirah-Ibrahim et al. 2018; Quah et al. 2021; Badli-Sham et al. 2023; Syafiq et al. 2023, 2024), only a few have focused on the disturbed forested areas (Badli-Sham et al. 2019; Fatihah-Syafiq et al. 2020; Komaruddin et al. 2020). Hence, there is a significant gap in knowledge on the herpetofauna of these habitats, which necessitates further study.

Within Terengganu, Bukit Maras (BM) is an isolated hill range surrounded by human settlements and agricultural matrix. Approximately 40% of the forested area at BM have been converted to orchards. The secondary forest in these hills regenerated after the land abandonment (about 15 years ago), therefore forming approximately 40% of secondary forest and the rest is untapped primary forest (PLANMalaysia 2024). Nonetheless, this forested area also faces the threat of deforestation due to current expansion of orchard areas. Given the alarming rate of habitat loss, these disturbances could severely impact herpetofauna species that may rely on these habitats as refugia.

Unfortunately, information on the biodiversity in this hill is virtually unknown. To our knowledge, there is only a single inventory study in BM which focused on the chiropteran species (Sulaiman and Chong 2011). Studies on the herpetofauna are completely missing. Therefore, this study aims to produce the first report of herpetofauna in BM. Bukit Maras is a non-protected area, thus this investigation could provide valuable information on what species inhabit BM before we lose them due to the deforestation.

Methods

Study area

Bukit Maras is situated in the Kuala Nerus district (max elevation: 329 metres a.s.l.), Terengganu, surrounded by human settlement and agricultural areas (Fig. 1). It has a total land area of approximately 2200 hectares, consisting of agricultural plots, secondary forests, and primary forests (underexplored) (Pejabat Daerah dan Tanah Kuala Nerus: https://pdtknerus.terengganu.gov.my/). This area experiences a warm and humid climate year-round, with a mean annual temperature of 26.7 °C. The month of May exhibits the highest average temperature, while January records the lowest. The region receives a substantial amount of precipitation, averaging 2736 mm annually (Izam et al. 2021).

Sampling had been done at three main sampling sites:

- Site 1 (5°25'20.98"N, 103°1'18.18"E) – This hill has a large soil road from the foothill to the summit as a hiking trekking trail. The landscape is characterized by an agricultural matrix and an open area for car parking at the foothill. Crop plantation areas also can be found along the trekking trails up to 200 meters. Examples of the planted crops are durian trees (*Durio* spp.), petai trees (*Parkia speciosa*), and banana plants (*Musa* spp.). Two disturbed small streams can be found in the agricultural areas, which originated from the intact secondary and primary forest.
- Site 2 (5°24'33.77"N, 103°1'27.63"E) – This hill also has a large soil road from the foothill to the summit as a hiking trekking trail. Oil palm and rubber plantations are the primary agricultural

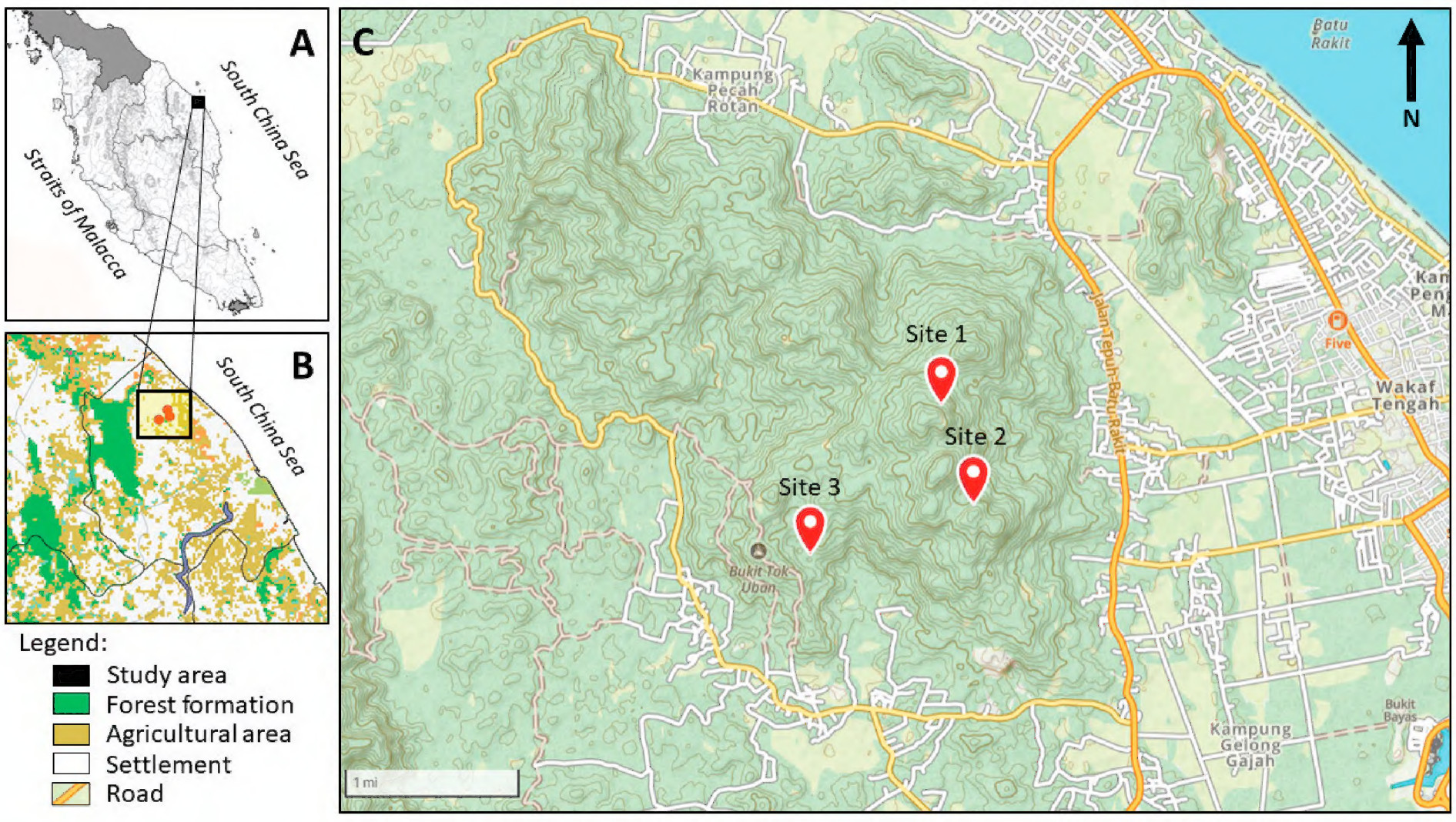

Figure 1. Map showing the location of Bukit Maras in Terengganu, Peninsular Malaysia (**A**), land cover types around BM (**B**), and the sampling sites (**C**).

Table 1. Habitat categories studied in Bukit Maras.

Habitat	Characteristics	Sampling Site	Sampling Point
Agricultural area	Mainly composed of durian (*Durio* sp.), banana (*Musa* sp.), petai (*Parkia speciosa*), oil palm (*Elaeis guineensis*) and rubber (*Hevea brasiliensis*) plantation. Scatteredly located from the foothill up to an elevation of 200 metres a.s.l.	Site 1, Site 2	4
Secondary forest	Forest remnants composed mainly of native species, unmanaged environment, with formation of understory and canopy.	All sites	4
Agricultural area stream	Small stream in the agricultural area with no canopy formation.	Site 1, Site 2	3
Secondary forest stream	Small stream in the agricultural area with canopy formation.	Site 1, Site 3	2

plantations here. Secondary forest vegetation situated mainly at the peak. A disturbed small stream flow through the agricultural area.

- Site 3 (5°24'35.4"N, 103°00'47.4"E) – This site is a secondary forest characterised by a small stream covered by a few dipterocarp tree species left undisturbed from deforestation in previous years. This site has the minimal disturbance compared to other two sites but the threat of deforestation for orchard expansion is imminent.

Sample collection and preservation

The surveys were conducted opportunistically from July 2019–October 2019, 4 July 2020, 12 July 2020, 26–27 July 2020, 17 October 2020, 12–14 November 2020, 1 November 2020, 26 November 2020, 28 November 2020, 15 January 2021 and between 31 December 2022 to 11 March 2023. Initially, pilot surveys were done opportunistically in 2019, and a systematic survey was planned for the subsequent years but due to the Covid 19 situation during the former years (2020–2021), the opportunistic surveys' approach was implemented at Bukit Maras to standardise the sampling effort. Surveyed areas spanned the disturbed and undisturbed small streams, secondary forests, and agricultural areas. The primary forest was left untapped due to its inaccessibility. We sampled 13 sampling points at all sites and later grouped them into four categories: agricultural area (**AA**), secondary forest (**SF**), agricultural area stream (**STA**), secondary forest stream (**STF**) (Table 1). We divided the habitat types into these four categories as we expect these four habitat types will consist of different species composition and demonstrate the importance of each habitat for this species. The streams are connected but were divided into agricultural stream and secondary forest stream due to clear difference in vegetation structure and composition.

To maximise the sampling effort, three types of collecting methods were employed: Visual Encounter Survey (VES), drift-fenced pitfall traps, and acoustic sampling. The samplings were executed during the day (10:00 to 13:00 h) and at night (20:00 to 23:00 h) to record both diurnal and nocturnal species. The VES activities were conducted with search parties consisting of three to four persons. A set of pitfall traps consisted of three 18 L buckets and aluminium zinc as the fence. The buckets were buried two meters apart from each other and were arranged in approximately straight lines. Two sets of pitfall traps were set up randomly at different locations. The first one was deployed at the foothill near the agricultural area, and the second set was deployed at the hilly area in the secondary forest. To increase the number of species detected, we also recorded the frog calls before we confirmed the species occurrence with the capture of the specimen. The recorded sound can be used for species-specific sound characteristic description in future study (Chan et al. 2020; Quah et al. 2021). A total of 816 man-hours (204 hours/person) were spent on the herpetofauna surveys.

Captured specimens were identified based on their morphological characteristics, following Berry (1975) and Badli-Sham et al. (2023) for amphibians, Grismer (2011) for lizards, Auliya (2007) for freshwater turtles and tortoises, and Das (2012) for snakes. Amphibian nomenclature follows the Amphibian Species of the World database (Frost 2024), while the reptile nomenclature follows The Reptile Database (Uetz et al. 2024). Only a few samples from a few species were taken for voucher specimens to minimise the extirpation of the current population (Table 2). We used the photographs of live specimen as evidence for each of the rest of the species that were not preserved as voucher specimens. Photographs of live specimens were taken with the Canon 3000D and Sony A6000 digital cameras. Euthanised voucher specimens were preserved with 10% formalin before being transferred into 70% ethanol for long-term storage and deposited at the General Biology Lab, Universiti Malaysia Terengganu, and catalogued under UMT Zoological Collection (**UMTZC**).

Table 2. List of voucher specimens from Bukit Maras catalogued with the UMTZC voucher code numbers.

Voucher No. (UMTZC)	Species Name
1701	*Gonocephalus liogaster*
1705	*Cyrtodactylus quadrivirgatus*
1706	*Phrynoides aspera*
1772	*Hylarana nicobariensis*
1773	*Calotes versicolor*
1774	*Eutropis multifasciata*
1882	*Cyrtodactylus consobrinus*
1823	*Hemiphyllodactylus typus*
1825	*Limnonectes deinodon*
1828	*Hylarana labialis*
1831	*Pseudorhabdion longiceps*

Figure 2. Habitat types in Bukit Maras. **A–D.** Agricultural area; **E.** Secondary forest; **F.** Stream at secondary forest; **G**, **H.** Stream at agricultural area.

Data analysis

To determine the adequacy of our sampling effort at BM and for both amphibian and reptile groups, individual-based and coverage-based rarefaction and extrapolation analysis was constructed using the "iNEXT" R package version 2.0.20 (Hsieh et al. 2016), with 100 bootstraps to estimate 95% confidence intervals. We used abundance data for this analysis. The estimated sample size for all curves (BM, amphibian, reptile) was set to be twice the sample size. The sampling achieves completeness when the individual-based rarefaction curve is plateauing. Meanwhile, the coverage-based rarefaction curve achieves completeness when the sample coverage is 1.0. This analysis uses Hill numbers of order q to compare the diversity of unequal sampling effort between two or more sites or groups (Chao et al. 2014). There are three types of order q for Hill numbers namely, species richness (q = 0), Shannon's diversity (q = 1) and Simpson's diversity (q = 3). We only utilised diversity order of species richness (q = 0) for this study as we aim to see the sampling effort in the perspective of species richness. We also used this analysis to compare the herpetofaunal diversity between the four habitat types. For the comparison of habitat types, we combined both amphibians and reptiles data as herpetofaunal data to utilize in the comparison analysis. Non-overlapping curves strongly indicate significant difference and vice versa for both individual-based and coverage-based rarefaction and extrapolation curves. While the abundance data used may be susceptible to double-counting individuals, this concern is less pronounced for continuously visible species like *Calotes versicolor* (Lovich et al. 2012). However, for less conspicuous species, such as secretive or infrequently observed ones, or those detected only by

calls, double-counting can be a more significant issue. To mitigate this, this study employed time-constrained visual and acoustic searches, and avoided recording species already observed or heard from the same location. In cases of ambiguity, data points were excluded.

For species-habitat network, we built two networks using both abundance and incidence data acting as links while habitat types and herpetofauna species acting as nodes (Marini et al. 2019). The nodes were arranged from the highest abundant/occurrence to the lowest abundant/occurrence. For the abundance-based habitat network analysis, there are two outcomes that are visualised: 1) site that is the most abundant to the lowest abundant 2) species that is the most abundant (dominant species) to the lowest abundant (rare species) sampled from all sites and how much contribution that species contribute to each site with respect to the abundance. For the incidence-based habitat network analysis, there are also two outcomes that are visualised: 1) site with the highest species richness 2) species with the highest occurrence to the lowest occurrence sampled from all sites. The analysis was performed using the "bipartite" R package version 2.17 (Dormann et al. 2009). All analyses were executed in RStudio software version 2024.04.1 (RStudio Team 2024).

Results

A total of 55 herpetofauna species from six amphibian families (Bufonidae – 2 spp., Dicroglossidae – 5 spp., Megophryidae – 3 spp., Microhylidae – 4 spp., Ranidae – 5 spp., Rhacophoridae – 4 spp.) and nine reptile families (Agamidae – 7 spp., Gekkonidae – 7 spp., Scincidae – 4 spp., Varanidae – 1 spp., Colubridae – 9 spp., Pythonidae – 1 spp., Viperidae – 1 spp., Trionychidae – 1 spp., Testudinidae – 1 spp.) were recorded in this study (Table 3) (Figs 3–5). Based on IUCN Redlist (2024), there is only single species (*Manouria emys*) listed under "Critically Endangered" status in this study, whereas the rest of the species are categorised as "Least Concern".

Table 3. A species checklist of amphibians and reptiles recorded in Bukit Maras and their IUCN status.

No	Taxa	IUCN
AMPHIBIANS		
Bufonidae		
1	*Duttaphrynus melanostictus* (Schneider, 1799)	LC
2	*Ingerophrynus parvus* (Boulenger, 1887)	LC
Dicroglossidae		
3	*Fejervarya limnocharis* (Gravenhorst, 1829)	LC
4	*Limnonectes blythii* (Boulenger, 1920)	LC
5	*Limnonectes deinodon* Dehling, 2014	LC
6	*Limnonectes hascheanus* (Stoliczka, 1870)	LC
7	*Limnonectes malesianus* (Kiew, 1984)	LC
Megophryidae		
8	*Leptobrachella sola* (Matsui, 2006)	LC
9	*Leptobrachium hendricksonii* Taylor, 1962	LC
10	*Pelobatrachus nasutus* (Schlegel, 1858)	LC
Microhylidae		
11	*Kaloula pulchra* Gray, 1831	LC
12	*Microhyla berdmorei* (Blyth, 1856)	LC
13	*Microhyla heymonsi* Vogt, 1911	LC
14	*Microhyla mantheyi* Das, Yaakob & Sukumaran, 2007	LC
Ranidae		
15	*Humerana miopus* (Boulenger, 1918)	LC
16	*Hylarana glandulosa* (Boulenger, 1882)	LC
17	*Hylarana labialis* (Boulenger, 1887)	LC
18	*Hylarana laterimaculata* (Barbour & Noble, 1916)	LC
19	*Hylarana nicobariensis* (Stoliczka, 1870)	LC
Rhacophoridae		
20	*Nyctixalus pictus* (Peters, 1871)	LC
21	*Polypedates discantus* Rujirawan, Stuart & Aowphol, 2013	LC
22	*Polypedates leucomystax* (Gravenhorst, 1829)	LC
23	*Theloderma licin* McLeod & Ahmad, 2007	LC
REPTILES		
LIZARDS		
Agamidae		
24	*Acanthosaura armata* (Gray, 1827)	LC
25	*Bronchocela cristatella* (Kuhl, 1820)	LC
26	*Calotes versicolor* (Daudin, 1802)	LC
27	*Draco sumatranus* Schlegel, 1844	LC
28	*Gonocephalus grandis* (Gray, 1845)	LC
29	*Gonocephalus liogaster* (Günther, 1872)	LC
30	*Leiolepis belliana* (Hardwicke & Gray, 1827)	LC
Gekkonidae		
31	*Cyrtodactylus consobrinus* (Peters, 1871)	LC
32	*Cyrtodactylus quadrivirgatus* Taylor, 1962	LC
33	*Gehyra mutilata* (Wiegmann, 1834)	LC
34	*Gekko monarchus* (Schlegel, 1836)	LC
35	*Hemidactylus frenatus* Duméril & Bibron, 1836	LC
36	*Hemidactylus platyurus* (Schneider, 1797)	LC
37	*Hemiphyllodactylus typus* Bleeker, 1860	LC
Scincidae		
38	*Dasia olivacea* Gray, 1839	LC
39	*Eutropis multifasciata* (Kuhl, 1820)	LC
40	*Lipinia vittigera* (Boulenger, 1894)	LC
41	*Lygosoma siamensis* Siler, Heitz, Davis, Freitas, Aowphol, Termprayoon & Grismer, 2018	LC
Varanidae		
42	*Varanus salvator* (Laurenti, 1768)	LC
SNAKES		
Colubridae		
43	*Ahaetulla prasina* (Boie, 1827)	LC
44	*Boiga cynodon* (Boie, 1827)	LC
45	*Dendrelaphis caudolineatus* (Gray, 1834)	LC
46	*Dendrelaphis cyanochloris* (Wall, 1921)	LC
47	*Dendrelaphis pictus* (Gmelin, 1789)	LC
48	*Dendrelaphis striatus* (Cohn, 1905)	LC
49	*Gonyosoma oxycephalum* (Boie, 1827)	LC
50	*Lycodon subcinctus* Boie, 1827	LC
51	*Pseudorhabdion longiceps* (Cantor, 1847)	LC
Pythonidae		
52	*Malayopython reticulatus* (Schneider, 1801)	LC
Viperidae		
53	*Tropidolaemus wagleri* (Boie, 1827)	LC
FRESHWATER TURTLE AND TORTOISE		
Testudinidae		
54	*Manouria emys* (Schlegel & Müller, 1844)	CR
Trionychidae		
55	*Dogania subplana* (Geoffroy Saint-Hilaire, 1809)	LC

Notes: IUCN STATUS: LC = Least Concerned; CR = Critically Endangered.

Figure 3. Amphibians from Bukit Maras. **A.** *Duttaphrynus melanostictus*; **B.** *Ingerophrynus parvus*; **C.** *Fejervarya limnocharis*; **D.** *Limnonectes deinodon*; **E.** *Leptobrachium hendricksonii*; **F.** *Pelobatrachus nasutus*; **G.** *Microhyla heymonsi*; **H.** *Microhyla mantheyi*; **I.** *Humerana miopus*; **J.** *Hylarana labialis*; **K.** *Polypedates leucomystax*; **L.** *Theloderma licin*.

The individual-based rarefaction and extrapolation curves for the total herpetofauna and each of amphibian and reptilian assemblages implied that only a few additional species can be detected in BM when more sampling efforts are executed as the extrapolated curves for all three showed a sign of plateauing (Fig. 6A). At the extrapolated curves, it is predicted that at least 60 species of herpetofauna may be found in BM; specifically, with additional efforts, an additional two species of amphibians and three reptiles are expected to be recorded. Coverage-based rarefaction and extrapolation curves are in accord with the individual-based rarefaction and extrapolation curves as the curves approaching the sampling completeness value (Fig. 6B). All curves are non-overlapped which indicated that the species richness ($q = 0$) for all curves is significantly different.

In general, *Calotes versicolor* had the highest abundance compared to other species in Bukit Maras. It also contributed the highest number of individuals in an agricultural area (AA). The AA is also the site with the highest abundance of herpetofauna. Species richness-wise, the secondary forest (SF) had the highest number of species among the habitats. *Fejervarya limnocharis* had the highest level of occurrence as it can be found across all four habitats. Each of the habitat types was composed of a different set of species composition (Fig. 7). To be specific, there are 36 species of herpetofauna in SF and the highest number of individuals is *Eutropis multifasciata* (12 individuals), followed by *Microhyla heymonsi* (11 individuals) and *Limnonectes hascheanus* (7 individuals). Meanwhile, AA had only 17 species and was dominated by *C. versicolor* (68 individuals), followed by *Hemidactylus frenatus* (17 individuals) and *Duttaphrynus melanostictus* (15 individuals). For riparian areas, the stream of the secondary forest (STF) had 16 species, and was dominated by *Limnonectes deinodon* (36 individuals), followed by *Hylarana labialis* (25 individuals) and *Leptobrachium hendricksonii* (16 individuals). On the other hand, the stream of agricultural area (STA) had only nine species,

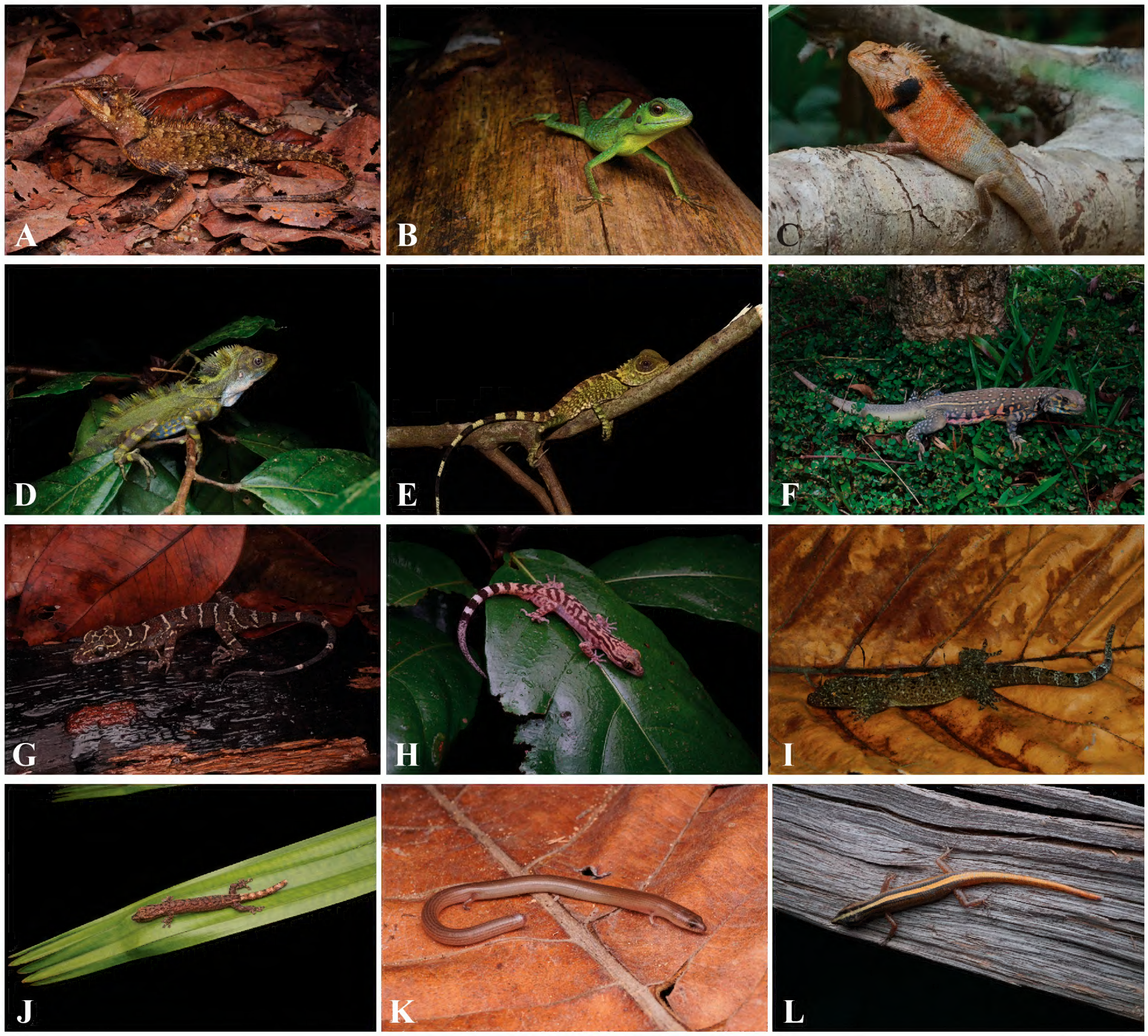

Figure 4. Lizards from Bukit Maras. **A.** *Acanthosaura armata*; **B.** *Bronchocela cristatella*; **C.** *Calotes versicolor*; **D.** *Gonocephalus grandis*; **E.** *Gonocephalus liogaster*; **F.** *Leiolepis belliana*; **G.** *Cyrtodactylus consobrinus*; **H.** *Cyrtodactylus quadrivirvgatus*; **I.** *Gekko monarchus*; **J.** *Hemiphyllodactylus typus*; **K.** *Lygosoma siamensis*; **L.** *Lipinia vittigera*.

dominated by *Polypedates leucomystax* (23 individuals), followed by *Fejervarya limnocharis* (19 individuals) and *H. labialis* (17 individuals) (see Suppl. material 1).

Based on Fig. 8, the diversity order of species richness (q = 0) for both curves for secondary forest (SF) and secondary forest's stream (STF) did not get to an asymptote even at the extrapolated curves, indicating that more species can be discovered in both habitats. On the other hand, both curves for the agricultural area (AA) and the agricultural area's stream (STA) showed an indication of levelling off at the extrapolated curves, indicating that the samplings in these areas are almost complete.

Discussion

The forested area at the human-induced landscape is disappearing at an unprecedented rate, leaving "islands" of forest remnants (Sodhi et al. 2010). This habitat may become refuge to the perturbed herpetofauna and our study demonstrated this by documenting a total of 55 species of herpetofauna in Bukit Maras. There are more than 500 species in Malaysia, with a total of 107 species recorded in Terengganu (Nur Amalina et al. 2017; Uetz et al. 2024). This indicates that this record is a preliminary checklist and there is a potential of adding new record of species in this baseline data, as corroborated by the non-asymptotic state of the individual rarefaction and extrapolation curves. The extrapolated curves indicated that an additional five herpetofauna species can be found with additional efforts. Some species of herpetofauna, particularly snakes, can be elusive and a previous study on temporal snake diversity in Terengganu suggested that surveys should be intensified, especially during the rainy season (Syafiq et al. 2023). This would not only increase the chance of encountering elusive snake species but also amphibian species (Badli-Sham et al. 2023).

Bukit Maras is a disturbed landscape dominated by secondary forest and agricultural areas. Herpetofauna are

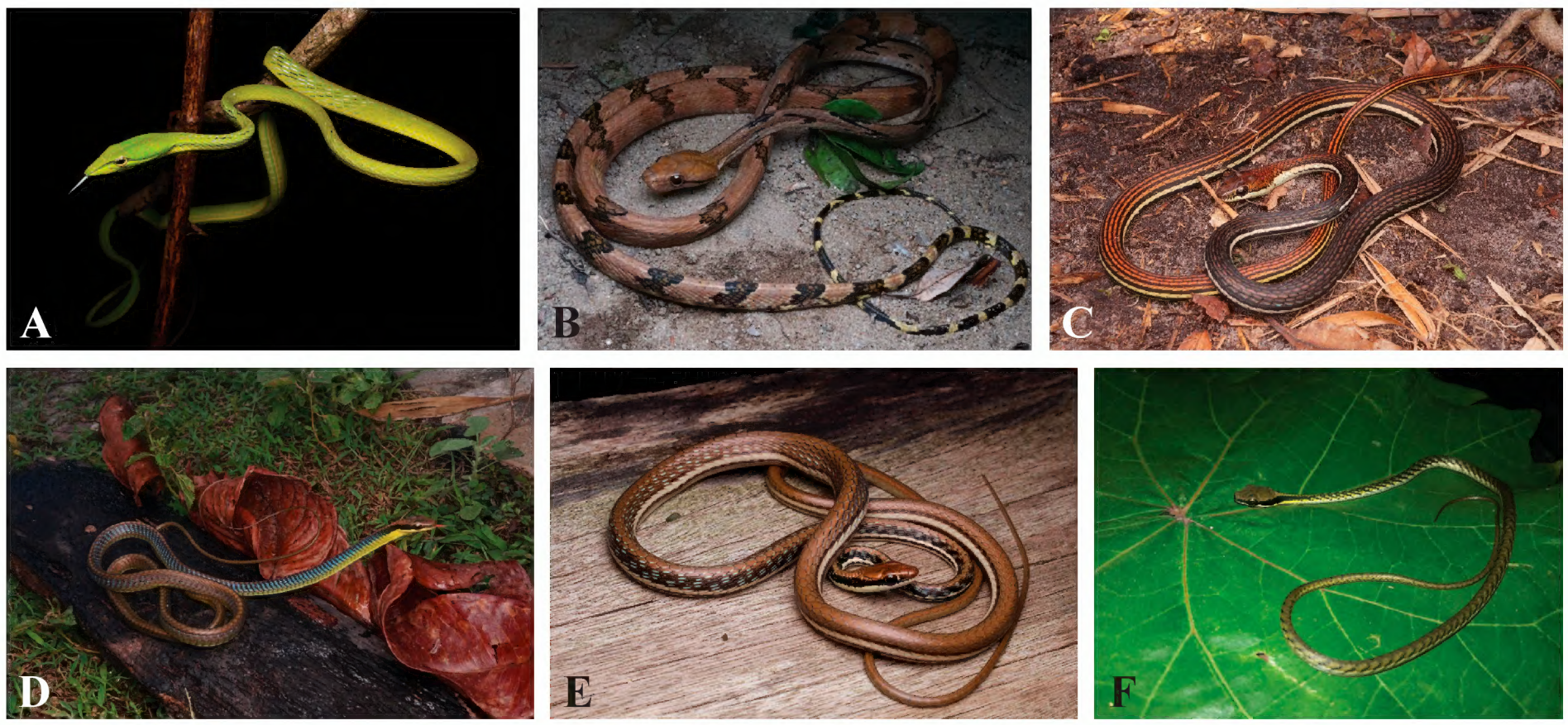

Figure 5. Freshwater tortoise and turtle and snakes from Bukit Maras. **A.** *Ahaetulla prasina*; **B.** *Boiga cynodon*; **C.** *Dendrelaphis caudolineatus*; **D.** *Dendrelaphis cyanochloris*; **E.** *Dendrelaphis pictus*; **F.** *Dendrelaphis striatus*; **G.** *Gonyosoma oxycephalum*; **H.** *Lycodon subcinctus*; **I.** *Malayopython reticulatus*; **J.** *Tropidolaemus wagleri*; **K.** *Manouria emys*; **L.** *Dogania subplana*.

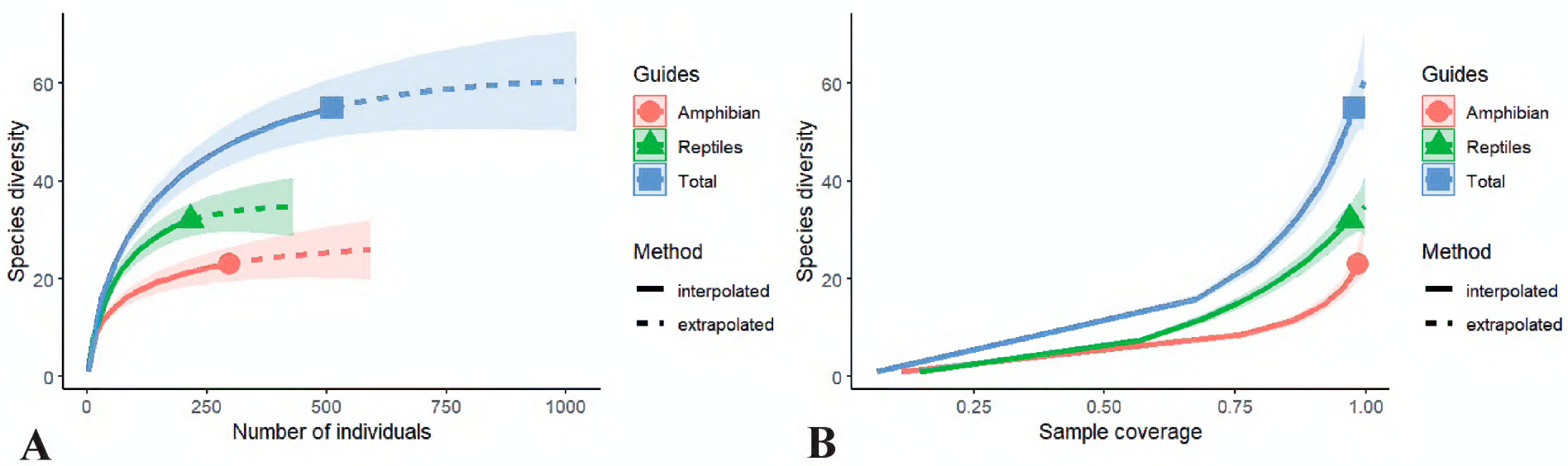

Figure 6. A. Individual-based rarefaction (solid line segment) and extrapolation (dotted line segment) sampling curves with 95% confidence interval (shaded areas) (left panel) and **B.** Coverage-based rarefaction (solid line segment) and extrapolation (dotted line segment) sampling curves with 95% confidence interval (shaded areas) (right panel) for herpetofauna sampled in Bukit Maras, Terengganu, Peninsular Malaysia.

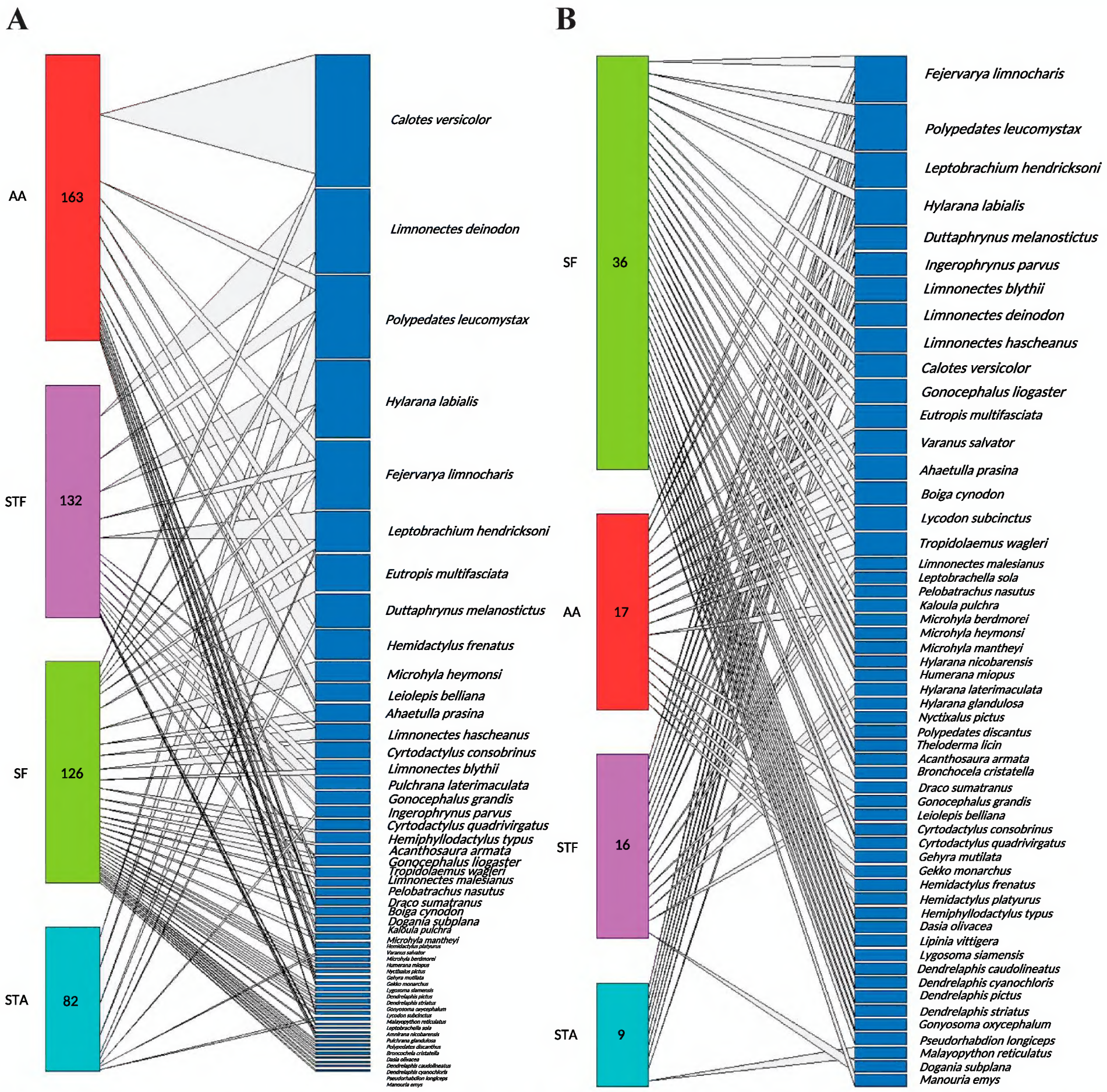

Figure 7. Species-habitat network in Bukit Maras. **A.** Abundance-based species-habitat network. The left panel represents nodes for habitat types while the right panel represents nodes for each species. The number of observed individuals for each site was written inside the nodes at right panel. **B.** Incidence-based species-habitat network. The left panel represents nodes for habitat types while the right panel represents nodes for each species. The number of observed species for each site was written inside the nodes at right panel. The nodes for both figures were arranged from the highest to lowest (abundance/frequency). For the clarity of the species name, see Suppl. material 1.

sensitive to land-use changes (Sodhi et al. 2008). The ongoing orchard expansion threatens the discovery of new species and the persistence of elusive ones. Our findings showed that secondary forests have higher herpetofauna diversity compared to agricultural areas (Fig. 8), aligned with findings from the previous research in Borneo (Gillespie et al. 2012). This difference is likely due to species loss in agricultural areas, where suitable habitat is limited. Forest-dwelling herpetofauna, known for their high site fidelity (Vitt and Caldwell 2001; Hillers et al. 2008), are particularly vulnerable to local extirpation in such modified habitats. Generalist species on the other hand, will be dominating the disturbed areas consequently (Gillespie et al. 2012; Faruk et al. 2013). Our results in the agricultural areas of Bukit Maras reflected this pattern. Without action to curb orchard expansion, biotic homogenisation, whereby species diversity is reduced and dominated by only a few common species, is a looming threat.

The presence of the critically endangered species, *Manouria emys* tortoise in the secondary forest highlights the high conservation value of Bukit Maras' remaining forests. This discovery underscores the urgency for

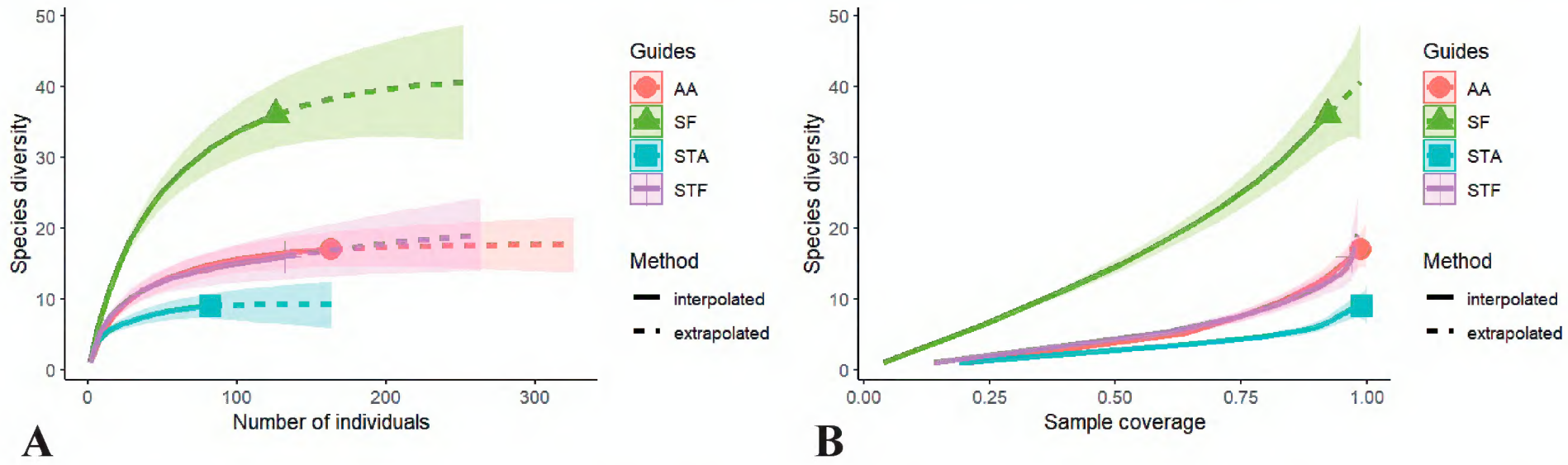

Figure 8. A. Individual-based rarefaction (solid line segment) and extrapolation (dotted line segment) sampling curves with 95% confidence interval (shaded areas) and **B.** coverage-based rarefaction (solid line segment) and extrapolation (dotted line segment) sampling curves with 95% confidence interval (shaded areas) for the herpetofauna data of four habitat types: green (secondary forest); red (agricultural area). The solid dots/triangles represent the reference samples. Note: AA = Agricultural Area, SF = Secondary Forest, STA = Agricultural Area Stream, STF = Secondary Forest Stream.

immediate action by policymakers, local authorities, and the public to protect these vital habitats.

Given the widespread occurrence of secondary forests around human settlements, practical conservation efforts should focus on preserving these areas and their riparian zones (Chazdon et al. 2009; Pirnat and Hladnik 2016). While not a perfect substitute for primary forests, secondary forests can support a significant diversity of herpetofauna (Thompson and Donnelly 2018). Their mix of vegetation and microhabitats from both primary and disturbed forests creates a more favourable environment for herpetofauna compared to other human-modified landscapes (Luja et al. 2008). Protecting these secondary forests can serve as a buffer zone, mitigating anthropogenic disturbances and safeguarding the remaining herpetofauna in Bukit Maras.

Conclusion

Our study helps to fill a critical knowledge gap by investigating the herpetofauna of isolated hills within Terengganu's human-modified landscape. This research focused on Bukit Maras, but similar isolated hills in Terengganu, such as Bukit Besar, Bukit Chendering, and Bukit Jong, warrant further investigation using similar methods. This study provides valuable baseline data of herpetofauna in Terengganu state and also can be used for future monitoring efforts to assess the impacts of environmental changes on herpetofauna in human-modified landscapes.

Authors' Contributions

Conceptualization: MFS, BHBS, ABA. Data curation: MFS, BHBS, SAF, MIMAW, FHA, GK, NNS, NFN, MS-R, JA, TKL, NSX, ABA. Investigation: MFS, BHBS, SAF, MIMAW, MAN, FHA, GK, NNS, NFN, MS-R, JA, TKL, NSX, MFA, SAR. Methodology: MFS, ABA. Resources: MFS, ABA. Supervision: ABA. Visualization: MFS, BHBS. Writing – original draft: MFS. Writing – review and editing: MFS, ABA.

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Supplementary material 1

Raw data and R codes

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Data type: docx

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